What is reliability engineering

No one disputes the need for engineered products to be reliable. The average consumer is acutely aware of the problem of less than perfect reliability in domestic products such as TV sets and automobiles. Organizations such as airlines, the military and public utilities are aware of the costs of unreliability. Manufacturers often suffer high costs of failure under warranty. Argument and misunderstanding begin when we try to quantify

period of time, particularly outside a warranty period. Even within a warranty period, the customer usually has no grounds for further action if the product fails once, twice or several times, provided that the manufacturer repairs the product as promised each time. If it fails often, the manufacturer will suffer high warranty costs, and the customers will suffer inconvenience. Outside the warranty period, only the customer suffers. In any case, the manufacturer will also probably incur a loss of reputation, possibly affecting future business.

Whether failures occur or not, and their times to occurrence, can seldom be forecast accurately. Reliability is therefore an aspect of engineering uncertainty. Whether an item will work for a particular period is a question which can be answered as a probability. This results in the usual engineering definition of reliability as:

The probability that an item will perform a required function without failure under stated conditions for a stated period of time.

Reliability can also be expressed as the number of failures over a period.

Durability is a particular aspect of reliability, related to the ability of an item to withstand the effects of time (or of distance travelled, operating cycles, etc.) dependent mechanisms such as fatigue, wear, corrosion,

WHAT DO RELIABILITY ENGINEERS DO?

- Implement Reliability Engineering Programs across all functions
  - Engineering
  - Research
  - manufacturing
  - Testing
  - Packaging
  - field service

The objectives of reliability engineering, in the order of priority, are:

1 To apply engineering knowledge and specialist techniques to prevent or to reduce the likelihood or frequency of failures.
2 To identify and correct the causes of failures that do occur, despite the efforts to prevent them.
3 To determine ways of coping with failures that do occur, if their causes have not been corrected.
4 To apply methods for estimating the likely reliability of new designs, and for analysing reliability data.

The primary skills that are required, therefore, are the ability to understand and anticipate the possible causes of failures, and knowledge of how to prevent them. It is also necessary to have knowledge of the methods that can be used for analysing designs and data. The primary skills are nothing more than good engineering knowledge and experience, so reliability engineering is first and foremost the application of good engineering, in the widest sense, during design, development, manufacture and service.

Mathematical and statistical methods can be used for quantifying reliability (prediction, measurement) and for analysing reliability data. The basic methods are described in Chapter 2, to provide an introduction for

Over-riding all of these aspects, though, is the management of the reliability engineering effort. Since reliability (and very often also safety) is such a critical parameter of most modern engineering products, and since failures are generated primarily by the people involved (designers, test engineers, manufacturing, suppliers, maintainers, users), it can be maximized only by an integrated effort that encompasses training, teamwork, discipline, and application of the most appropriate methods. Reliability engineering "specialists" cannot make this happen. They can provide support, training and tools, but only managers can organize, motivate, lead and provide the resources. Reliability engineering is, ultimately, effective management of engineering.

considerations all increase the risks of product development. Figure 1.1 shows the pressures that lead to the overall perception of risk. Reliability engineering has developed in response to the need to control these risks.

Later chapters will show how reliability engineering methods can be applied to design, development,

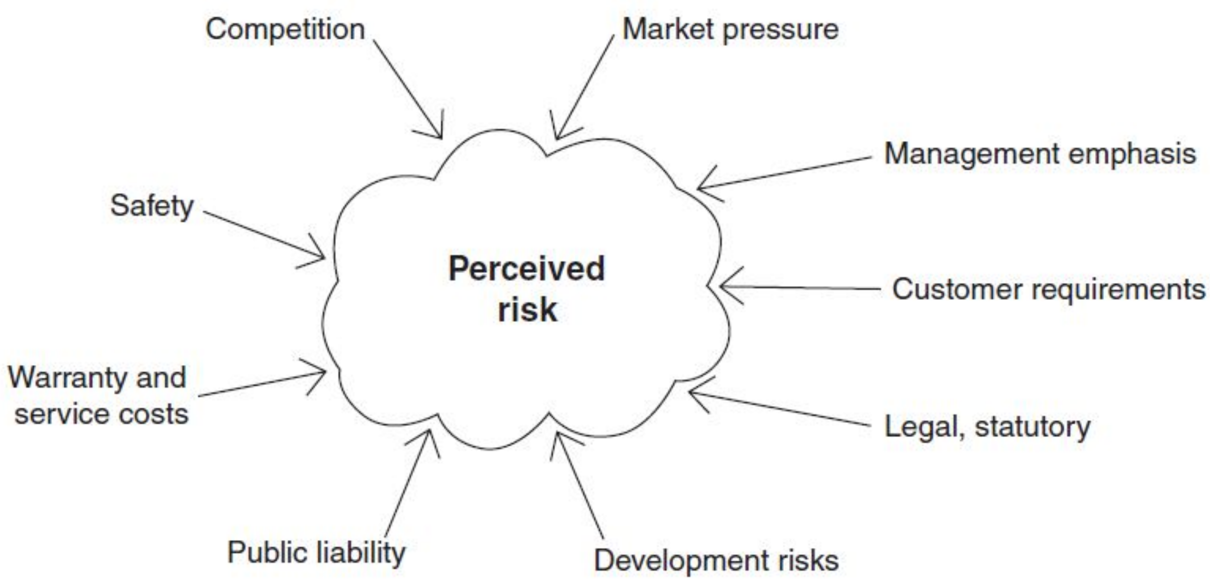


Figure 1.1 Perception of risk.

Performance, Quality, and Reliability

Performance is usually associated with the functionality of a product—what the product can do and how well it can do it. For example, the functionality of a camera involves taking pictures. How well it can take pictures and the quality of the pictures involves performance parameters such as pixel density, color clarity, contrast, and shutter speed.

Performance is related to the question, "How well does a product work?" For

Reliability is associated with the ability of a product to perform as intended (i.e., without failure and within specified performance limits) for a specified time in its life

cycle. In the case of the camera, the customer expects the camera to operate properly for some specified period of time beyond its purchase, which usually depends on the purpose and cost of the camera. A low-cost, throwaway camera may be used just to take one set of pictures. A professional camera may be expected to last (be reliable) for decades, if properly maintained.

"To measure quality, we make a judgment about a product today. To measure reliability, we make judgments about what the product will be like in the future" (Condra 2001). Quality in this way of thinking is associated primarily with manufacturing, and reliability is associated mostly with design and product operation. Figure 1.5 shows the role of quality and reliability in product development.

Product quality can impact product reliability. For example, if the material strength of a product is decreased due to defects, the product reliability may also be decreased, because lower than expected life-cycle conditions could cause failures. On the other hand, a high-quality product may not be reliable, even though it conforms to workmanship specifications. For example, a product may be unable to withstand environmental or operational conditions over time due to the poor selection of materials, even though the materials meet workmanship specifications. It is also possible that the workmanship specifications were not properly selected for the usage requirements.

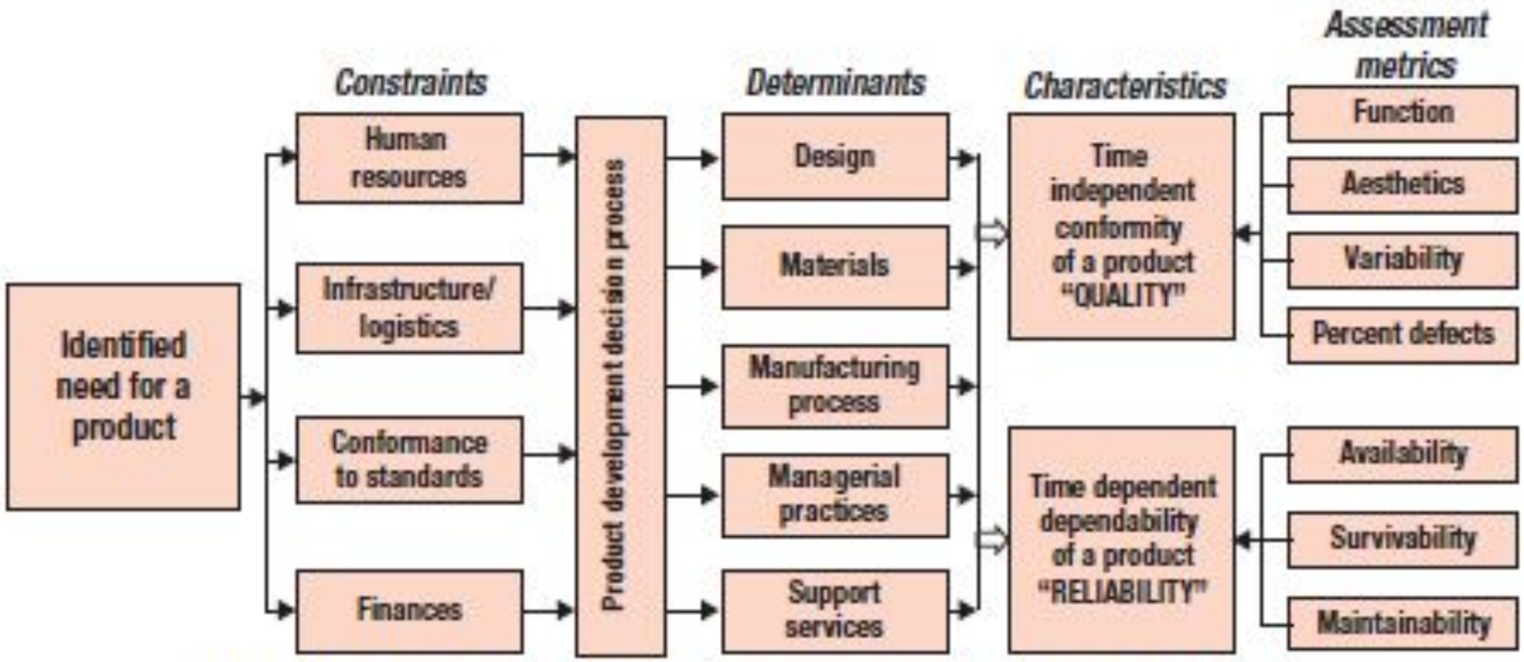


Figure 1.5 Quality and reliability inputs and outputs during product development.

Why Do Engineering Products Fail?

The main reasons why failures occur are:

1 The design might be *inherently incapable*. It might be too weak, consume too much power, suffer resonance at the wrong frequency, and so on. The list of possible reasons is endless, and every design

2 The item might be *overstressed* in some way. If the stress applied exceeds the strength then failure will occur. An electronic component will fail if the applied electrical stress (voltage, current) exceeds the ability to withstand it, and a mechanical strut will buckle if the compression stress applied exceeds the buckling strength. Overstress failures such as these do happen, but fortunately not very often, since designers provide margins of safety. Electronic component specifications state the maximum rated conditions of application, and circuit designers take care that these rated values are not exceeded in service. In most

the properties of the materials being used (e.g. ultimate tensile strength) and they ensure that there is an adequate margin between the strength of the component and the maximum applied stress. However, it might not be possible to provide protection against every possible stress application.

3 Failures might be caused by *variation*. In the situations described above the values of strength and load are fixed and known. If the known strength always exceeds the known load, as shown in Figure 1.2, then failure will not occur. However, in most cases, there will be some uncertainty about both. The actual strength values of any population of components will vary: there will be some that are relatively strong, others that are relatively weak, but most will be of nearly average strength. Also, the loads applied will be variable. Figure 1.3 shows this type of situation.

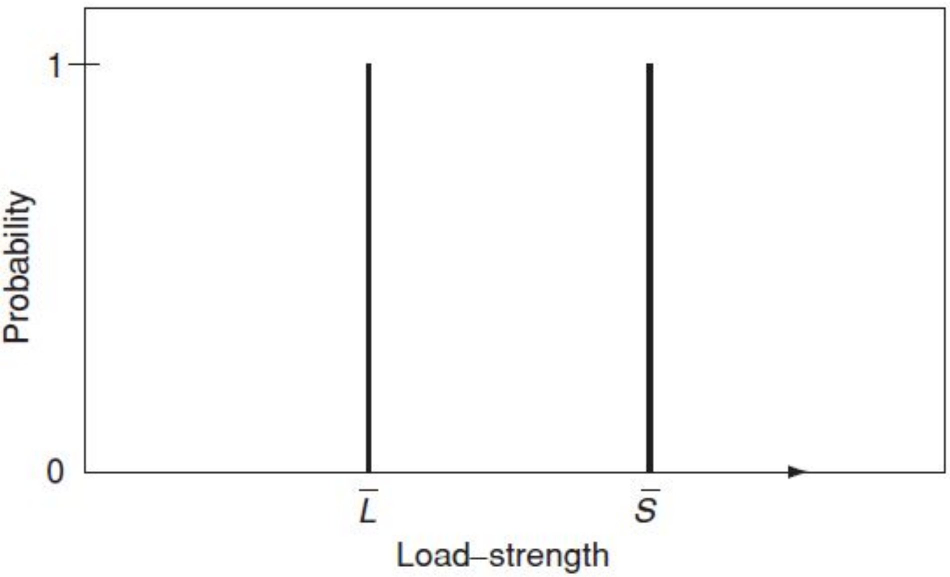


Figure 1.2 Load–strength – discrete values.

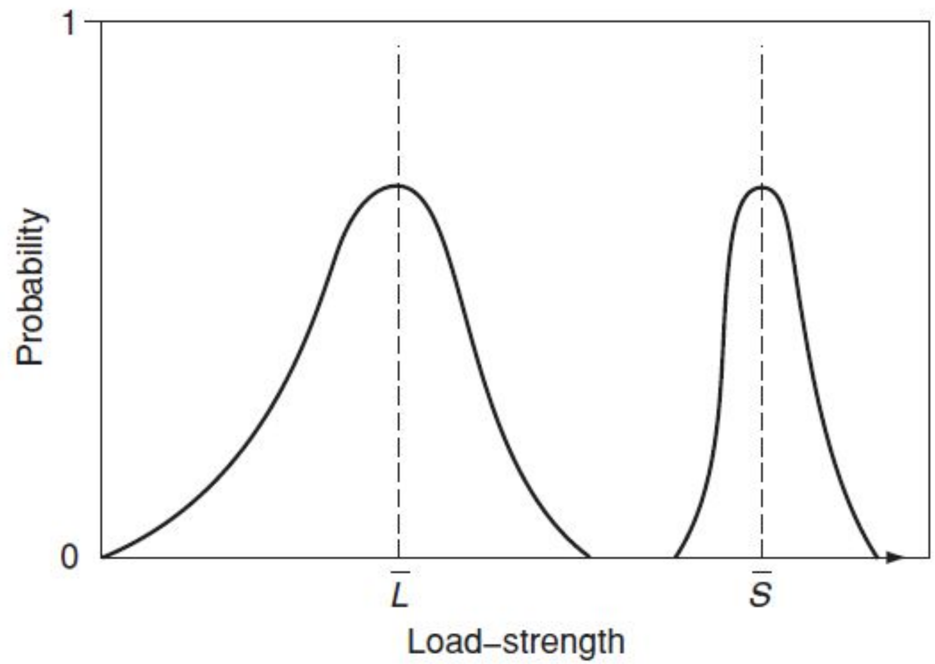


Figure 1.3 Load–strength – distributed values.

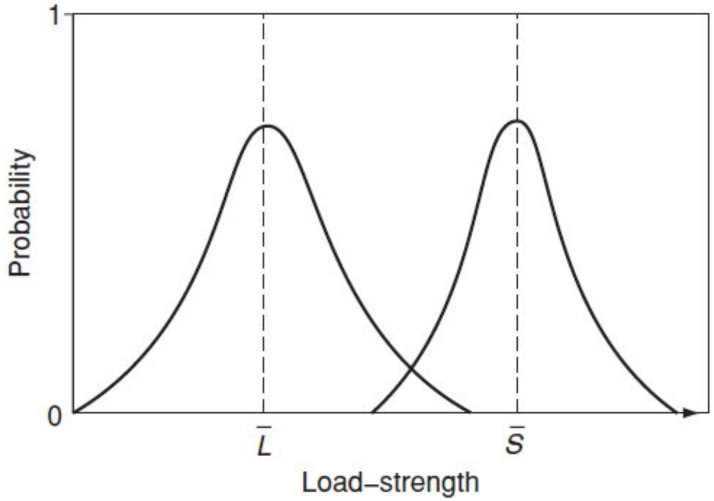


Figure 1.4 *Load–strength – interfering distributions.*

However, if there is an overlap between the distributions of load and strength, and a load value in the high tail of the load distribution is applied to an item in the weak tail of the strength distribution so that there is overlap or *interference* between the distributions (Figure 1.4), then failure will occur.

Failures can be caused by *wearout*. We will use this term to include any mechanism or process that causes an item that is sufficiently strong at the start of its life to become weaker with age. Well-known examples of such processes are material fatigue, wear between surfaces in moving contact, corrosion, insulation deterioration, and the wearout mechanisms of light bulbs and fluorescent tubes. Figure 1.5 illustrates this kind of situation. Initially the strength is adequate to withstand the applied loads, but as weakening occurs over time the strength decreases. In every case the average value falls and the spread of the strength distribution widens. This is a major reason why it is so difficult to provide accurate predictions of the lives of such items.

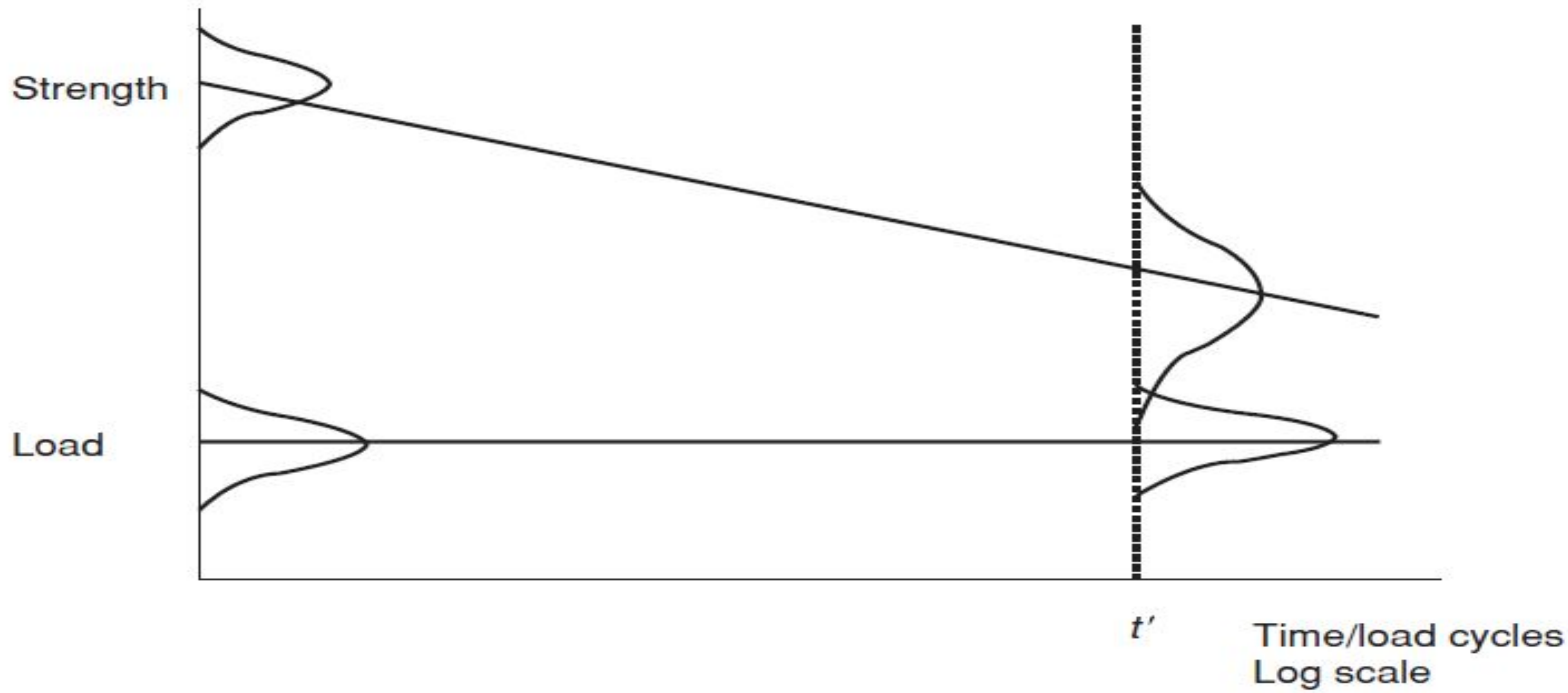


Figure 1.5 *Time-dependent load and strength variation.*

5 Failures can be caused by other time-dependent mechanisms. Battery run-down, creep caused by simultaneous high temperature and tensile stress, as in turbine discs and fine solder joints, and progressive drift of electronic component parameter values are examples of such mechanisms.

6 Failures can be caused by *sneaks*. A sneak is a condition in which the system does not work properly even though every part does. For example, an electronic system might be designed in such a way that under certain conditions incorrect operation occurs. The fatal fire in the Apollo spacecraft crew capsule was caused in this way: the circuit design ensured that an electrical short circuit would occur when a particular sequence was performed by the crew. Sneaks can also occur in software designs.

7 Failures can be caused by *errors*, such as incorrect specifications, designs or software coding, by faulty assembly or test, by inadequate or incorrect maintenance, or by incorrect use. The actual failure mechanisms that result might include most of the list above.

8 There are many other potential causes of failure. Gears might be noisy, oil seals might leak, display screens might flicker, operating instructions might be wrong or ambiguous, electronic systems might suffer from electromagnetic interference, and so on.

Failures have many different causes and effects, and there are also different perceptions of what kinds of events might be classified as failures. The burning O-ring seals on the Space Shuttle booster rockets were not classed as failures, until the ill-fated launch of Challenger. We also know that all failures, in principle and almost always in practice, can be prevented.

Other Measures of Reliability

Availability is used for repairable systems

- It is the probability that the system is operational at any random time t.

- It can also be specified as a proportion of time that the system is available for use in a given interval (0,T).

Other Measures of Reliability

Mean Time To Failure (MTTF): *It is the average time that elapses until a failure occurs.*
It does not provide information about the distribution of the TTF, hence we need to estimate the variance of the TTF.

Mean Time Between Failure (MTBF): *It is the average time between successive failures.*
It is used for repairable systems.

Bathtub curve(LIFE-CYCLE CURVE AND PROBABILITY DISTRIBUTIONS IN MODELING RELIABILITY)

The **bathtub curve** is widely used in reliability engineering. It describes a particular form of the hazard function which comprises three parts:

- The first part is a decreasing failure rate, known as early failures.
- The second part is a constant failure rate, known as random failures.
- The third part is an increasing failure rate, known as wear-out failures.

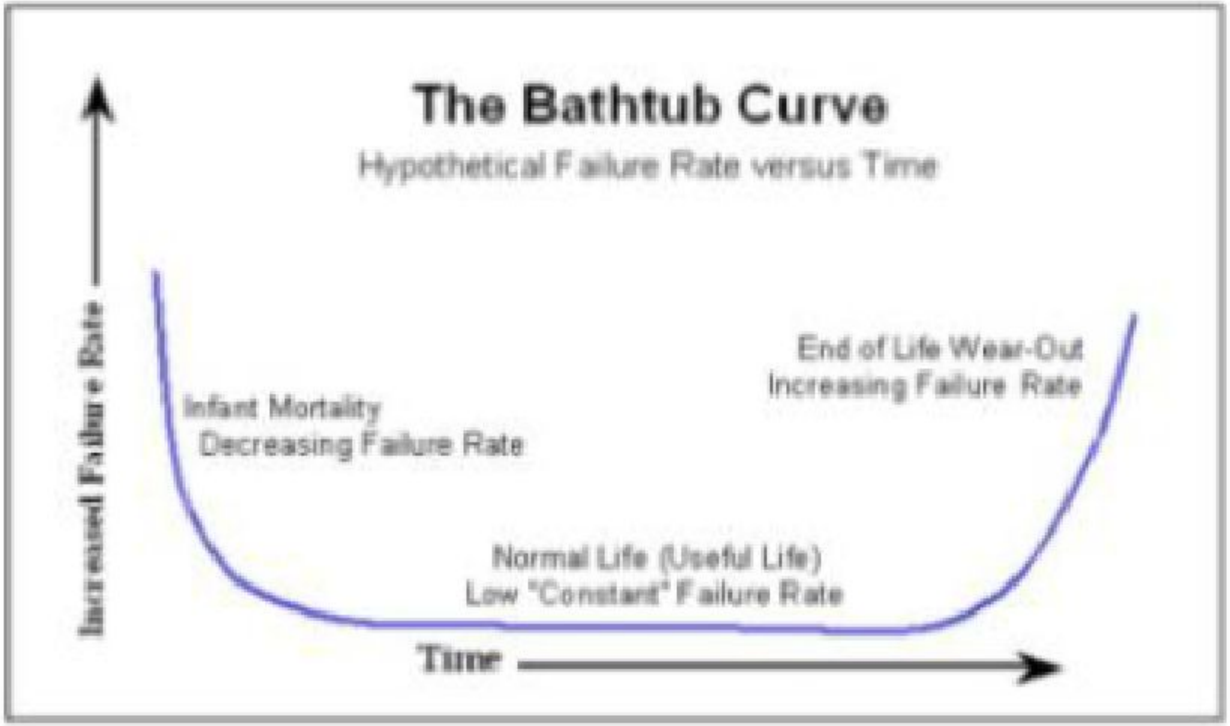
The name is derived from the cross-sectional shape of a bathtub: steep sides and a flat bottom.

The bathtub curve is generated by mapping the rate of early "infant mortality" failures when first introduced, the rate of random failures with constant failure rate during its "useful life", and finally the rate of "wear out" failures as the product exceeds its design lifetime.

In less technical terms, in the early life of a product adhering to the bathtub curve, the failure rate is high but rapidly decreasing as defective products are identified and discarded, and early sources of potential failure such as handling and installation error are surmounted. In the mid-life of a product—generally speaking for consumer products—the failure rate is low and constant. In the late life of the product, the failure rate increases, as age and wear take their toll on the product. Many electronic consumer product life cycles strongly exhibit the bathtub curve

- In general, some components have well defined failures; others do not.
- In the beginning, when the item or component is installed, the item fails with high frequency, which is known as initial failure or infant mortality.
- These are generally due to manufacturing defects. They are very high at initial stages and gradually decreases and stabilize over a longer period of time.

* Therefore the whole pattern of failures could be depicted by a bathtub curve



- Stable or constant failures due to chance can be observed on an item for a longer period.

- These types of failures are known as random failures and characterized by constant number of failures per unit of time.

- Due to wear and tear with the usage, the item gradually deteriorates and frequency of failures again increases.

- These types of failures are called as wear-out failures. At this stage failure rate seems to be very high due to deterioration.

Probability Distributions to Model Failure Rate Exponential Distribution

The exponential model, with only one unknown parameter, is the simplest of all life distribution models. The key equations for the exponential are shown below:

PDF: $f(t, \lambda) = \lambda e^{-\lambda t}$

CDF: $F(t) = 1 - e^{-\lambda t}$

Reliability: $R(t) = e^{-\lambda t}$

Failure Rate: $h(t) = \lambda$

Mean: $\frac{1}{\lambda}$

Median: $\frac{\ln 2}{\lambda} \cong \frac{0.693}{\lambda}$

Variance: $\frac{1}{\lambda^2}$

Note that the failure rate reduces to the constant λ for any time. The exponential distribution is the only distribution to have a constant failure rate. Also, another name for the exponential mean is the **Mean Time To Fail** or **MTTF** and we have MTTF = $1/\lambda$.

An amplifier has an exponential time-to-failure distribution with a failure rate of 8% per 1000 hours. What is the reliability of the amplifier at 5000 hours? Find the mean time to failure.

What is the highest failure rate for a product if it is to have a probability of survival (i.e., successful operation) of 95% at 4000 hours? Assume that the time to failure follows an exponential distribution.

REPAIRABLE AND NON-REPAIRABLE ITEMS

- It is important to distinguish between repairable and non-repairable items when predicting or measuring reliability
- For a non-repairable item such as a light bulb, a transistor, a rocket motor or an unmanned spacecraft, reliability is the **survival probability** over the item's expected life, or for a period during its life, **when only one failure can occur**.
- During the item's life the instantaneous probability of the first and only failure is called the **hazard rate.**

REPAIRABLE AND NON-REPAIRABLE ITEMS

- Life values such as the mean life or mean time to failure (MTTF), or the expected life by which a certain percentage might have failed (say 10 %.) (percentile life), are other reliability characteristics that can be used.
- Note that non-repairable items may be individual parts (light bulbs, transistors, fasteners) or systems comprised of many parts (spacecraft, microprocessors).

REPAIRABLE AND NON-REPAIRABLE ITEMS

- For items which are repaired when they fail, reliability is the probability that failure will not occur in the period of interest, when more than one failure can occur.
- It can also be expressed as the rate of occurrence of failures (ROCOF), which is sometimes referred as the failure rate (usually denoted as λ).
- However, the term failure rate has wider meaning and is often applied to both repairable and non-repairable systems

REPAIRABLE AND NON-REPAIRABLE ITEMS

- For non-repairable parts failure rate is expressing the number of failures per unit time, as applied to one unit in the population, when one or more failures can occur in a time continuum.
- It is also sometimes used as an averaged value or practical metric for the hazard rate.
- Repairable system reliability can also be characterized by the mean time between failures (MTBF), but only under the particular condition of a constant failure rate.

REPAIRABLE AND NON-REPAIRABLE ITEMS

- It is often assumed that failures do occur at a constant rate, in which case

$$Failure\,rate(\lambda) = \frac{1}{(MTBF)}$$

- However, this is only a special case.
- It is valuable because it is often true and because it is easy to understand.
- Sometimes an item may be considered as both

REPAIRABLE AND NON-REPAIRABLE ITEMS

- For example, missile is repairable system when it is in store and subjected to scheduled tests, but it becomes non-repairable when it is launched.
- Reliability analysis of such systems must take account of these separate states.
- Repairability might also be determined by other considerations. For example, whether electronic circuit board is treated as a repairable item or not will depend upon the cost of repair.
- An engine or a vehicle might be treated as repairable only up to a certain age.

REPAIRABLE AND NON-REPAIRABLE ITEMS

- Another concerned in reliability is the availability of repairable items, since repair takes time.
- Availability is affected by the rate of occurrence of failures (failure rate) and by maintenance time.
- Maintenance can be corrective (i.e. repair) or preventive (to reduce the likelihood of failure, e.g. lubrication).
- We therefore need to understand the relationship between reliability and maintenance, and how both reliability and maintainability can affect availability.

DURABILITY

- Durability is a particular aspect of reliability, related to the ability of an item to withstand the effects of time (or of distance travelled, operating cycles, etc.) dependent mechanisms such as fatigue, wear, corrosion, electrical parameter change, and so on.
- Durability is usually expressed as a minimum time before the occurrence of wearout failures.
- In repairable systems it often characterizes the ability of the product to function after repairs.

A semiconductor fabrication plant has an average output of 10 million devices per week. It has been found that over the past year 100,000 devices were rejected in the final test.

(a) What is the unreliability of the semiconductor devices according to the conducted test?

(b) If the tests reject 99% of all defective devices, what is the chance that any device a customer receives will be defective?